2008 PAPER 1 : SOLUTIONS AND MARK SCHEME

Students who obtain 20 ,or more, marks receive a merit certificate

1. $\frac{1}{2} mv^2 = m c \Delta\theta + mL$ (2)

   $v^2 = 2 c \Delta\theta + 2L$
   $v^2 = 2 \times 126 \times 300 + 2 \times 21{,}000$ (1)
   $v = 340 \, ms^{-1}$ (1)

   [TOTAL 4]

2. The reading changes when the force changes. The force on the balance is applied by the weight of the bucket and water and fish. None of these weights can change, but if the fish has a VERTICAL component of ACCELERATION then it pushes the water, which exerts a force on the balance.

   (2)

   [TOTAL 2]

3. The Empire State Building has a centre of mass point that is determined by its mass distribution. What this results in is that there is some point within the building such that if an axis passes through that point in any direction, then in a perfectly uniform gravitational field the whole building could be rotated about the axis and it would be balanced. This is particularly clear if the axis is horizontal and the building was tipped over a little; the top of the building would balance the bottom.
   However, the earth's gravitational field is not uniform, but is radial from the direction of the centre of the earth. Therefore the field is stronger at the base of the building and so the centre of gravity is a little below the centre of mass (a very small amount)

   (2)

   [TOTAL 2]

4. Two balls per second with 5 balls implies 2½ seconds per cycle (1)
   ½ second in the hands so 2 seconds in the air for each ball (1)
   1 second going up and 1 second falling (1)
   $s = \frac{1}{2}gt^2 = \frac{1}{2}9.81x1^2 = 4.9\,metres$ (1)

   [TOTAL 4]

5. (a) As the air temperature is below zero, the water at the surface of the pond will cool down. The water at the surface therefore becomes denser and will sink. This continues until all the water in the pond is at a few degrees above zero. Then the water at the surface will cool down to freezing point and solidify. The water below the surface will lose heat slowly by conduction to the surface, not by convection; the water at the bottom of the pond will be the last to cool down to zero and then finally freeze.

   (2)

   (b)
   i. As the temperature is raised from 0 °C, the length of the column decreases and then increases (1)
   ii. A graph of length against temp with a single minimum in it. (1)

   (c) $V_1 = 1+aT_1+bT_1^2$
   $V_2 = 1+aT_2+bT_2^2$
   When T = 0 °C then $V_1 = V_2$ (1)
   Also $V_1 = V_2$ when $aT_1+bT_1^2 = aT_2+bT_2^2$ (1)

   So $0 = a(T_1-T_2) + b(T_1^2-T_2^2)$

   i.e. $0 = a(T_1-T_2) + b(T_1-T_2)(T_1+T_2)$

with solution $T_1 = T_2$ (trivial) or $T_1+T_2 = -a/b$

i.e. $T_1+T_2 = 7.985\ ^\circ C$ (1)

and with $T_1 = 0^\circ C$ then $T_2 = 7.895^\circ C$

and this is the range over which the readings are not single valued. (1)

(d)

$$\left.\begin{aligned} \frac{dV}{dt} &= a + 2bT \\ So\ 0 &= a + 2bT_d \\ T_d &= -\frac{a}{2b} = 3.95\ ^\circ C \end{aligned}\right\} \text{ or } \left\{\begin{aligned} V &= 1+aT+bT^2 \\ &= b(T + a/2b)^2 + 1 - a^2/(4b) \\ &\text{So V shortest when} \\ T_d &= -a/(2b) = 3.95\ ^\circ C \end{aligned}\right\}$$

(2)

[TOTAL 10]

6. Substituting into $R^2=N\lambda^2$

We obtain $25 \times 10^{40} = N \times 9 \times 10^{36}$

$N = 2.8 \times 10^4$ changes of direction as it crosses the galaxy

(1)

$$time = \frac{distance}{speed} = \frac{N\lambda}{c} = \frac{2.8x10^4 x3x10^{18}}{3x10^8} = 2.8x10^{14}\ seconds$$ (3)

[TOTAL 4]

7. (a)

$$R_2 \text{ in parallel with } R\ (R_2 // R) \text{ has the value } \frac{R_2 R}{R_2 + R}$$

$$V = E\frac{(R_2 // R)}{R_1 + (R_2 // R)}$$

$$V = E\frac{R_2 R}{(R_2 + R)\left(R_1 + \frac{R_2 R}{(R_2 + R)}\right)}$$

$$\frac{V}{E} = \frac{R_2 R}{R_1(R_2 + R) + R_2 R} = \frac{R_2 R}{R_1 R_2 + R(R_1 + R_2)}$$

(4)

(b)

$$I = \frac{V}{R_2} = E\frac{R}{R_1 R_2 + R(R_1 + R_2)}$$

$$\frac{1}{I} = \frac{1}{ER}(R_1 R_2 + R(R_1 + R_2))$$

(2)

(c)

$$\frac{1}{I} = \frac{1}{ER}\left[\rho^2 \ell(L - \ell) + R\rho L\right]$$

(2)

(d)

Which is at a maximum when $\ell(L - \ell)$ is a maximum

i.e. when $\ell = L/2$ either by observation or symmetry argument or by calculus

or by completing the square : $l(L-l) = L^2/4 - (L/2 - l)^2$. (2)

[TOTAL 10]

8. (a)

$$E = \frac{hc}{\lambda} = \frac{6.6x10^{-34} x3x10^8}{120x10^{-9}} = 1.65x10^{-18}\ J$$

$$Number\ of\ photons = \frac{20}{1.65x10^{-18}} x3600 = 4.4x10^{22}\ photons\ per\ hour$$

(2)

(b)

$$momentum\ of\ a\ single\ photon = E/c = \frac{1.65x10^{-18}}{3x10^{8}} = 5.5x10^{-27}\ kg\ m\ s^{-1}$$

$$momentum\ change\ per\ second = 5.5x10^{-27}\ x\frac{4.4x10^{22}}{3600} = 6.7x10^{-8}\ kg\ m\ s^{-1}$$

This is equal to the force on the bulb i.e. $6.7x10^{-8}\ N$

(2)

(c)

$$acceleration = \frac{F}{m} = \frac{6.7x10^{-8}}{0.20} = 3.3x10^{-7}\ m\ s^{-2}$$

(1)

(d)

Only the number of photons per second changes

$$So\ Power\ of\ bulb = 20x\frac{9.81}{3.3x10^{-7}} = 0.59\ GW$$

(1)

[TOTAL 6]

9. (a) This is partly an exercise in setting out the work in a tabular form so that the data can be referred to in support of the later comment. Marks for setting out the calculations in a systematic manner should be awarded.

(2)

for 450 nm

$9 \times 450 \times 10^{-9} = 0.2 \times 10^{-3} \times \sin\theta_9$ $\theta_9 = 1.160°$

$10 \times 450 \times 10^{-9} = 0.2 \times 10^{-3} \times \sin\theta_{10}$ $\theta_{10} = 1.289°$

for 495 nm

$9 \times 495 \times 10^{-9} = 0.2 \times 10^{-3} \times \sin\theta_9$ $\theta_9 = 1.276°$

$10 \times 495 \times 10^{-9} = 0.2 \times 10^{-3} \times \sin\theta_{10}$ $\theta_{10} = 1.418°$

(2)

For 450 nm the angular separation is 0.13° (0.129°)
For 495 nm the angular separation is 0.14° (0.142°)

(2)

(b)

θ_9 increases by 10%
θ_{10} increases by 10%

and the difference between θ_9 and θ_{10} increases by 10%

Because both θ_9 and θ_{10} are small angles then $\sin(\theta)$ can be approximated by θ (in radians).
It is not the small difference that makes the small angle approximation.

(2)

[TOTAL 8]

BPhO PAPER 1 MERIT CERTIFICATES

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